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Pure-tone sound at 15,750 Herz generated by flyback transformers in many computer and video display terminal (VDT) monitors has stress-related productivity effects in some operators, especially women. College-age women in a controlled experiment simulating half a normal work day showed responses within the first half hour of exposure to a tone generator-created pure-tone. Overall productivity decreased 4.47% in the first half hour and 8.18% in the second hour. Effects of the tone varied with time in the menstrual cycle, high estrogen levels further decreasing performance. Control and experimental groups (N=100) were analyzed. These findings make a direct link between a specific attribute of VDTs and stress symptoms reported in workplace health studies. Because women hear frequencies one to three kiloHertz higher than men and find sounds "too loud" at half the loudness men tolerate, they are more at risk for these stress symptons. (32 references) (Author/DB)

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COMPUTER PURE-TONE AND OPERATOR STRESS:

REPORT III

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Caroline Dow and Douglas C. Covert

Presented to the Newspaper Division, Association for Education in Journalism and Mass Communication, Minneapolis, Minn., August 12, 1990.

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ABSTRACT

COMPUTER PURE-TONE AND OPERATOR STRESS:

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Pure-tone sound at 15,750 Herz generated by flyback transformers in many computer and VDT monitors has stress-related productivity effects in some operators, especially women. College-age women in a controlled experiment simulating half a normal work day showed responses within the first half hour of exposure to a tone generator-created pure-tone. Overall productivity decreased 4.47 percent in the first half hour and 8.18 percent in the second hour. Effects of the tone varied with time in the menstrual cycle, high estrogen levels decreasing performance further. Control and experimental groups (N=100) were analyzed.

These findings make a direct link between a specific attribute of VDTs and stress symptoms reported in workplace health studies. Because women hear frequencies one to three kiloHerz higher than men and find sounds "too loud" at half the loudness men tolerate, they are more at risk for these stress symptoms.

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COMPUTER PURE-TONE AND OPERATOR STRESS: REPORT III

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Past and current research into causes of health problems in computer and VDT operators, including physiological and psychological stress, has concentrated on ionizing and nonionizing radiation. Most recently, extremely low frequency radiation and consequent electromagnetic fields have been targeted as potential sources of biological problems and other effects.[1]

As a result of the emphasis on electromagnetism, a commonly recognized source of stress in the working environment may have been overlooked: noise.

The stressful noise is not ordinary noise at an excessive level, but a pure-tone sound near the upper range of human hearing generated by most common computer monitors. Experimental research reported here suggests that there is increased stress with measurable effects on productivity in an environment where this 16 kHz pure-tone is present.

The literature has documented that headaches, uncommon fatigue, irritability and some vision problems in VDT operators have resisted alleviation through changing the physical environment of the workplace. There is growing evidence that stress caused by near-ultrasonic sound emanating from computer and VDT terminals is an important contributor.[2]

Reports in the popular press and in publications of working organizations such as The Society of Professional Journalists and the Organization of Working Women (9-5) suggest that problems in the computerized workplace are especially acute among women. There has been much speculation that computer use has, in some way, contributed to miscarriages and other gynecological problems which several studies have found associated with computerized workplaces around the country.[3] Some of these sex-based physiological problems are known to be exacerbated by stress.

Monitor as Source

A flyback transformer in computer monitors (and television sets) enables the electronic system to write an image on the viewing screen. This transformer produces a pure-tone sound in the upper range of human hearing, generating nonionizing radiation at 15,750 Herz in most current models of VDT and computer viewing monitors. It is commonly called 16 kiloHerz (kHz) radiation and is in an acoustic range sometimes known as "very low frequency" (VLF).

VLF nonionizing radiation is usually perceived to be electrical. However, it is clear that terminology distinctions must be made between **audio pressure** waves and **electromagnetic** waves. Radio waves below 30 kHz, including a 16 kHz frequency, are in the VLF band.

It is easy for researchers to become confused in labelling and discussing the 16 kHz frequency. Both **audio pressure** waves and **electromagnetic** (radio) waves are called nonionizing radiation and discussed in terms of frequency and length of wave. Although both may be called VLF radiation, note that one wavelength of a 16 kHz acoustic wave is about 1/16 inch or 2 millimeters, whereas one wavelength of a 16 kHz radio wave is about 5,000 meters.

Audio or acoustic pure-tone frequencies near the high end of the range audible to humans, just below frequencies usually identified as ultrasonic (above the human hearing range), should not be treated as if they were electromagnetic radiation.

The audio band representing the range of normal human hearing is generally considered to be between 20 Hz and 20 kHz, although few people can hear sounds in the top of this range. In terms of human hearing range, a 16 kHz tone is quite high in frequency.

AMA Survey

The Council on Scientific Affairs of the American Medical Association has summarized the literature on health effects and

VDTs,[4] but the report tended to confuse VLF radio frequencies and audio frequencies in its discussions.

The AMA Council report dismissed noise as a factor in the health effects of VDT exposure. "Depending on the internal location of the transformer, very little exposure could be expected for an operator seated at the front. The amount of noise, even at the source, could be reduced to near zero with component shielding."[5]

Measurements conducted for a 1987 survey, in October and November of 1988 in preparation for an earlier controlled experiment, and again in March 1990 for this experiment indicated, however, that the sound was almost equal on all sides of the monitor and in some cases was greater at the front than at the sides or back.[6] Furthermore, retrofitting existing machines to alleviate the 16 kHz noise would be difficult,[7] although shielding from electromagnetic radiation could be effective. Again, it seems the Council report confused audio waves and electromagnetic VLF waves.

These same measurements also indicate that changes in dB readings increase by about 45 to 48 percent as the distance is shortened from the test distance of one meter to an operator distance of about 1/2 meter. But, from one meter outward in measured rooms diminish at an unusually low rate, less than 15 percent over the next 10 meters.

The Council's report referred to sound levels, then discounted sound as a health factor: "High levels of VLF

ultrasound (79 to 150 dB) in industry have been reported to cause symptoms that include temporary hearing loss, nausea, fatigue, headache, and tinnitus. However, the highest reported VLF sound level from VDTs is only 68 dB."[8] The bandwidth at 68 decibels (dB), broadband or pure-tone, was not reported in the AMA summary.

The Council's "highest reported" sound level came from the Bureau of Radiological Health (BRH) report which gave a peak of 68 dB at 40 kHz, and 61 dB at 16 kHz,[9] 14 dB below the limit (75 decibels) recommended by the International Labor Office and adopted by the World Health Organization in 1977 for 16 kHz and higher frequencies.[10] The BRH reported on 14 different monitor brands, with 16 kHz sound levels ranging from 41-61 dB at the operator's position. (See Table A-4.)

These limits on sound exposure were established to avoid damage to human hearing, not to reduce stress effects.

Human Response to Noise

Noise is difficult to define except in the most general terms, such as "any undesireable sound (or signal)."[11] Also, it is necessary to distinguish between meaningful noise, which people may associate with some recognizable phenomenon, and meaningless noise such as the white noise of hearing science, unrecognizable sounds not associated with any familiar phenomenon, or sounds which become meaningless over time such as those of air handling systems. To be objectionable, noise must

reach a certain loudness level. The objectionable loudness level varies, however, with frequency or complexity or both.[12]

Meaningful noise may cause stress reactions when first encountered, but humans soon accommodate when the noise is complex, of short duration and repeated often enough. However, noise without meaning may induce significant physiological changes, even upon repetition,[13] and the eyes may lose the speed with which they adjust focus on near and far objects and move through certain angles.[14]

Either continuous or periodic noise may cause people to become tired or irritable, even if it is not extremely loud, and human response to noise is difficult to predict. A continuous, pure tone is not as well tolerated as the variable, wide-range tones and fluctuating sound intensities of ordinary living and working quarters. ". . . pure tones, especially at high frequencies, are much more annoying than a broadband noise at the same level."[15] High-pitched pure tones are irritating in any environment.[16] Signal/noise ratios do not generally apply to pure-tones unless the competitive noise is very loud relative to the pure-tone signal, approaching twice the dB readings.

Studies have found that "subjective effects are often only reported by the young females among a working population" and attributed this to more sensitive hearing of the higher frequencies in this group.[17]

One frequently noted study found women in an industrial setting experienced stress disease symptoms while exposed to a 16

kHz sound output. The symptoms were relieved by enclosing the offending industrial machines in sound-damping boxes.[18] It found women more susceptible to distressing physiological symptoms from the 16 kHz sound than men, but then discounted this sex difference.

Loudness, Frequency and Sex Differences

The ordinary living room, when unoccupied, has an average decibel level of about 25 dB, rising to about 45 dB when there is common activity including ordinary conversation. An office environment may average 60 to 65 dB depending on its machines. A sound level "of 60 dB would pose some difficulty in telephone use and would require raising the voice in order to have intelligible conversation for talker-listener distances of 3 ft, and a loud voice for talker-listener distances of 7 ft."[19] Conversation at 60dB is comfortable for most people, but noise or competitive sound at the same sound pressure level (SPL) is not.

Loudness. Age and sex factors should enter into studies of acoustic radiation effects, but commonly have been ignored. Loud or too-loud noises are generally subjective descriptions and we can become accustomed to some meaningful loud noises, but physiological differences between men and women produce notable differences in their criteria for "too loud."

In the normal range of ambient sound frequencies, women identify broad-band noise as too-loud at levels 8 to 10 decibels below that of men.[20] The logarithmic decibel scale makes

intuitive comparisons difficult, but this difference in subjective perceptions of auditory excess means that men do not identify sounds as "too loud" until they are two or more times as loud as the limit for women.[21] There is no reason to believe that a similar difference does not occur at higher but still audible frequencies.

All of the studies surveyed by the AMA Council on Scientific Affairs were concerned with hearing damage, not stress disease. None of the studies supporting these standards considered sex-differences or hormonal changes in hearing range or loudness perception; the standards were intended to apply to men and women alike.

Hearing range (frequency). Normal human hearing lies within the 20 to 20,000 Hz range. Men in their 20s and 30s ordinarily do not hear frequencies much above about 15 kHz. Women in the same age range hear frequencies 1 to 3 kHz above men.[22] Therefore, the 16 kHz sound emanating from monitors is more likely to affect women than men due to differences in their hearing range. There is an age-related decrease in pure-tone sensitivity, but at any age, the sensitivity to high frequency sounds is higher in women than in men.[23] Therefore, young women are more likely to experience consequences than older women or young men.[24]

Hormonal effects. Furthermore, limited tests also indicate a variation in sensitivity to high-frequency sound with changes in sex hormone levels, in both men and women but particularly in women.[25] Young women at peaks (high estrogen levels) of their

menstrual cycle, pregnant or taking many forms of birth control pills will be most sensitive and susceptible to the effects of pure-tone sound at the higher frequencies.[26]

It has been common in the literature to refer to "subjective effects" of headache, fatigue, etc, usually described as occurring at sound pressure levels above 76 dB. The subjective-effects complaints have been discussed as physical or recognizably physiological with the apparent assumption that the onset is sudden, with no prelude, as if suddenly crossing a threshold. The irritation and fatigue reported by VDT operators could well be precursive symptoms of the physical subjective effects reported at higher sound pressure levels, especially with the increased auditory acuity of women.

Differential Response Identified

An earlier (1989) experiment using the same subjects with and without the pure-tone treatment indicated a differential response to the presence of a 16 kHz pure tone resulting in reduced productivity as measured through speed and accuracy of performance.[27] It was hypothesized that this effect was a consequence of stress induced by the tone, and that the effects might be exacerbated by the relative estrogen levels of the women subjects.

EXPERIMENTAL ASSUMPTIONS

Two principal assumptions were made in designing the experiment reported here. The first was that differences in productivity (both speed and accuracy of performance) would reflect differences in stress experienced by the control and experimental groups. The only difference between the two test environments was the presence of a 16 kHz pure tone in the experimental room. (No computers were present in either room.)

The second assumption was derived from suggestions in the 1989 experiment that estrogen levels influenced productivity when subjects were exposed to the 16 kHz tone. The literature indicated that sensitivity of women to high frequency sounds increases at high estrogen levels. Experimental results were thus expected to show heightened sensitivity to the sound, emphasizing any lowered productivity in the experimental group, for those women at or near estrogen peaks.

The women were asked to report the time in weeks since the onset of their last menstrual period. For the purposes of this experiment, it was assumed that a report of the second and fourth weeks would encompass the average high estrogen levels and the first and third weeks would encompass lows. Those responding "now" were recorded as in the first week. While inexact, this measure was considered sufficient and is in keeping with the general indications in the literature.[28]

METHODOLOGY

Volunteer, healthy young women subjects were recruited from the student body of the University of Evansville to take part in this controlled experiment. All the volunteers signed Informed Consent Forms. The subjects were screened for general health and, especially, for any signs of menstrual irregularity or potential pregnancy.

Although no federal funding was involved, the protocols of 45 CFR 46 of the Department of Health and Human Services were followed rigorously. The university's institutional review board not only scrutinized the informed consent form but also the procedures to be followed in screening, testing and data collection.

Subjects

The volunteer subjects were randomly assigned to two groups, control and experimental. Volunteers arriving as cohorts were also divided between the groups on a randomized basis. Screening questions indicated that the accepted volunteers would be considered emotionally stable by their friends and their families.

Data analysis showed no differences between the two groups on any of the indicators -- including grade-point average in high school and in college, age, or year in school -- nor any of the other measures collected in the entry and exit questionnaires.

Because many of the concerns about VDTs and women workers are related to reproductive health, volunteers were screened for their menstrual history and excused from participation if there were any reported irregularities or potential pregnancies.

A total of 102 subjects were recruited; two were excused based on the screening questions.

Experimental Environment

Two, identical, windowless classrooms were used for the test environment. All furnishings in both rooms were the same. No computers were present in either room.

For the experimental group, a specially constructed tone generator provided a pure tone at 16 kHz. The generator was adjusted to a random SPL (sound pressure level) output range of 42.3 dB at 13 meters to 44.6 dB at two meters, the farthest and nearest possible subject positions. Direct frontal measurements from the farthest subject, 13 meters, was 42.1 dB and from three meters, the nearest subject during testing, 49.1 dB.

The SPL average was selected to represent the range of levels emitted from most VDTs and computer monitors used in U.S. work places at normal working distances as recorded in the literature.

Performance Requirements

Subjects were asked to demonstrate their ability to perform both accurately and productively on tests simulating the Graduate

Record Exam, a demanding test for any undergraduate. This test was divided into sections: three verbal, two quantitative and two analytical.

The experimental session simulated half of a "normal" work day, beginning at 8:30 a.m. (Saturday, 31 March 1990) with a half-hour orientation and entry questionnaire (with no 16 kHz tone present), and concluding at 11:57 a.m. with an exit questionnaire. The total period was divided in half by a 10-minute break. Each half is referred to here as a "sitting." Half of each group began with two verbal sections while the other half began with a quantitative followed by an analytical section. The second sitting had the "quantitative" subjects begin with the verbal sections.

Attrition

Subjects had been told that, while they should do their best to complete the total session, this was an experiment about stress and they could leave at any time if they found they were feeling excessively stressful. Four subjects (8%) in the experimental group left at the break, complaining about feeling physically ill. They claimed to have felt "normal" at the beginning of tne testing and during the orientation. No subjects left the control group.

RESULTS

The earlier experiment (1989) indicated a differential response to the hypothesized tone-induced stress. Nonparametric measures were used to analyze the data. The current (1990) tests demonstrated that the presence of the pure tone does affect productivity of the test subjects within the first half-hour of exposure ($p<.05$) and that susceptibility to the tone-stress varies with the place in the estrogen cycle ($p<.05$).

In addition, paired-samples dependent-measures t-tests indicated a fall in productivity when the sound was present ($p<.10$).

The other measures of central tendency and analysis of variance continued to show the same patterns of the 1989 same-subjects paired-measures tests. The presence of the tone caused the women to speed up, a stressor in itself, and make more errors. Otherwise, there were no statistically significant differences between the control group and the experimental group using the customary measures of central tendency or analysis of variance using all non-experimental indices.

In the current experiment, the control group was remarkably stable in its performance throughout the morning. The fluctuations in the experimental group indicate that the 16 kHz pure tone can be considered a stress producer.

Overall Comparisons

Table 1 reports overall performance, but for subsequent comparisons, the first two verbal sections, taken in sequence, were used as the principal measures of both speed and accuracy. Time-task ratios (the number of seconds for each question completed) and time-accuracy ratios (seconds for each correct answer) were also calculated.

Table 1.
Overall Performance
All Sections and Sittings
(Excludes attrition losses in totals)

	Control Mean	SD	Experimental Mean	SD	Diff. means
Total correct answers, four completed sections	58.23	13.45	57.63	12.38	-0.60
Sum of correct verbals	34.60	9.33	33.00	8.78	-1.60
Total completions	157.81	30.27	162.56	25.98	+4.75
Total errors	86.10	24.58	90.98	23.60	+4.88
Time-task ratio, total completions (lower is better)	51.29	10.10	49.26	8.31	-2.03
Time-accuracy ratio (lower is better)	179.26	41.67	194.47	65.02	+15.21

The error rate and speed of performance follow the same general pattern for the groups as the 1989 experiment, with errors increasing and speed also increasing. In the 1989 experiment, subjects scored near the top of the scale with easy

exercises. The questions in this test were much more difficult and subjects averaged near the middle of the scale.

Earlier tests had shown likelihood of a threshold in exposure time before effects of the tone would appear. Duration of exposure to the 16 kHz pure tone shows effects within the first hour when verbal performance is separated into first and second sittings (Table 2). There is also a notable compression of the variation in the experimental group.

Table 2.
Verbal Performance by Sitting

	Control Mean	SD	Experimental Mean	SD	Diff. means
First sitting					
Sum of verbals	34.59	10.21	33.63	9.70	-0.96
Completions	86.19	14.93	91.21	10.88	+5.02
Errors	41.41	10.21	42.38	9.70	+0.97
Time-task ratio	43.24	8.63	40.09	5.32	-3.15
Second sitting					
Sum of verbals	34.62	8.07	32.40	7.74	-2.22
Completions	98.62	11.78	100.72	8.23	+2.10
Errors	41.38	8.07	43.60	7.74	+2.22
Time-task ratio	43.33	6.19	42.02	3.97	-1.31

The quantity of work completed by the experimental group increased by 5.82 percent in the first sitting but increased less

in the second sitting. The average number of errors in the experimental group increased by 5.36 percent in the second sitting.

Time-accuracy ratios, an index of productivity, also show a decrease in efficiency in the experimental group, especially in verbal performance (Table 3).

Table 3.
Time-Accuracy Ratios
(Low is Higher Productivity)

	Control Mean	SD	Experimental Mean	SD	Diff. Means
All completed sections	179.26	41.67	183.65	41.10	4.39
1st sitting, all Ss	83.00	22.92	91.81	32.74	8.81
attrition excluded			86.98	23.82	3.98
2nd sitting	99.26	28.20	97.62	23.23	-1.64
Verbal					
1st sitting	86.40	26.11	90.26	33.70	3.86
2nd sitting	97.46	23.31	105.43	30.15	7.97

The second-sitting increases in the control group over their performance in the first sitting may be attributed to fatigue.

Sectional Comparisons

Dividing the data by section and by sitting shows the effect of the tone on verbal performance over the total testing period (Table 4).

Table 4.
Verbal Performance
By Section and Sitting

	Control Mean	SD	Experimental Mean	SD	Diff. means
Sec. 1, Sitting 1	17.22	4.95	16.25	5.13	-0.97
Sec. 2, Sitting 1	17.37	6.28	17.38	5.09	+0.01
Sec. 1, Sitting 2	17.43	4.39	15.76	4.68	-1.67
Sec. 2, Sitting 2	17.19	4.34	16.64	4.27	-0.55

The control group was remarkably stable over the half-day period with mean scores differing by only 0.24. Means of the experimental group differed by 1.62, a difference from high to low score of 9.32 percent.

Regression Analysis

Preliminary regression analysis of all cases indicated four factors making major contributions to the variances: college grades, presence of the 16 kHz tone, first or second sitting (fatigue) and time in the menstrual cycle (high or low estrogen). College grades were, of course, the major predictor (Table 5).

Table 5.
Verbal Performance, Regression

	All Cases	
	Beta	F
College grades	0.33959	11.387
16 kHz tone	-0.07590	0.596
Sitting	-0.09090	0.833
Menstrual time	0.07832	0.619

	Control		Experimental	
	Beta	F	Beta	F
College grades	0.38195	7.851	0.24367	2.810
Sitting	-0.12369	0.792	-0.14153	1.007
Menstrual time	0.31226	5.152	-0.21762	2.247

Menstrual time influence. When separated into control and experimental groups (Table 5), another factor shows a major influence: the time in the menstrual cycle. The control group showed a strong positive influence of menstrual time -- the estrogen peaks -- whereas the experimental group showed a strong negative influence. The change of sign is also present in the quantitative and analytical sections of the test (Table 6).

Table 6.
Quantitative and Analytical Performance, Regression

	All cases	
	Beta	F
College grades	0.31353	9.951
16 kHz tone	0.12574	1.635
Sitting	-0.05475	0.305
Menstrual time	0.02395	0.059

	Control		Experimental	
	Beta	F	Beta	F
College grades	0.26042	3.147	0.34702	6.338
Sitting	-0.01105	0.005	-0.12727	0.888
Menstrual time	0.15740	1.129	-0.12183	0.780

Median Test

A further demonstration of the effects of estrogen levels on verbal performance using the Median Test shows a significant effect of estrogen level on verbal performance when the tone is present for both total score and the score on the second section, always completed after the first section. The no-sound group showed no statistical significances. (Table 7.)

Table 7.
Verbal Performance
Median Test by Estrogen Level

Experimental		Low estrogen	High estrogen
Total verbal			
	GT	20	4
Median 33			
	LE	14	11

Chi-square = 3.116, p<.10; Fisher's 2-tailed p=0.078.

Experimental		Low estrogen	High estrogen
Section 1 verbal			
	GT	13	3
Median 18			
	LE	21	12

Experimental		Low estrogen	High estrogen
Section 2 verbal			
	GT	20	3
Median 17			
	LE	14	12

Chi-square = 4.836, p<.05; Fisher's 2-tailed p=0.028.

Control		Low estrogen	High estrogen
Total verbal			
	GT	10	11
Median 34			
	LE	19	7

Control		Low estrogen	High estrogen
Section 1 verbal			
	GT	11	12
Median 17			
	LE	18	6

Control		Low estrogen	High estrogen
Section 2 verbal			
	GT	12	10
Median 17			
	LE	17	8

Moses Test of Extreme Reaction

The Moses Test of Extreme Reaction (the range of responses) showed no significances when all cases were analyzed for the effect of the 16 kHz tone on verbal scores, nor when high estrogen cases were analyzed. However, low estrogen cases showed significant effects of the increased intensity of effort on the second verbal section (Table 8).

Table 8.
Verbal Performance, Extremes
Low Estrogen Level and 16 kHz Tone

Control	Experimental			H = 1	
		Span	1-tailed p	Span	1-tailed p
29	34	63	1.000	48	0.011

Matched Pairs

Pairs were subsequently matched on the three dimensions of grade point, menstrual time and age. Section 1 comparison then gave a $t=1.592$, $p<.10$, showing the effects of the tone within the first half-hour.

ANALYSIS AND DISCUSSION

Results of the 1989 and 1990 controlled experiments give enough support to reject the null hypothesis that there is no effect from the 16 kHz pure tone generated by many VDTs and computer monitors found in workplaces and classrooms in the U.S. Women in both the control and experimental groups were matched in all

ways. In 1989 they were the same individuals; in 1990 they were statistically equal on all indices.

Consistency in the control group performance, as demonstrated in tables 4 and 7, not only offers an excellent contrast with the experimental group but also demonstrates the high stability of the testing instrument for these women.

Non-parametric tests of performance data in the experiment reported here indicate that this pure tone does in fact affect productivity in women during and after the first half hour of exposure, and that susceptibility to the tone-stress effect varies with the time in the individual estrogen cycle.

The central tendency tests for the control and experimental groups, while not statistically significant for this half-day level, continue to demonstrate tne same patterns found in the 1989 paired-measures tests. The presence of the 16 kHz pure tone results in a speeding up of performance (a recognized stressor) and an increase in error rate.

When the 1990 control and experimental groups were paired by grades and estrogen levels, sources of within-group variance, the two dependent-group sample t-test was significant at $p<.10$. Given the statistical significances of the Median and Moses tests, this is a clear indicator of the effect of the tone.

Overall Productivity

Overall productivity as indicated by the time-accuracy ratios (Table 1) fell 8.48 percent with the presence of the tone.

On the verbal portions of the test (Table 3), productivity declined by 4.47 percent in the first hour and by 8.18 percent in the second hour from the control group performance.

Duration

It is clear from the sequential performance shown in Table 4, and with matched pairs, that the experimental group, differing only in the addition of the 16 kHz tone, was affected by the conditions of the experimental environment.

The 1989 experiment suggested a threshold of about one-half hour for effects of the tone to be expressed in performance. This experiment shows effects in less than the half-hour. If there is a threshold, it may be affected by the difficulty of the task.

Intensity Response

The experimental group's performance in the first section was worse than performance in the second section, in both sittings. These women were young, healthy and highly motivated. The increase in performance on Section 2 was likely due to an effort to compensate for the stress by concentrating on their work, speeding up but at the same time making more errors. Even with this compensation, when the women were paired by grade point and estrogen level (high or low), the tone caused a significant fall in productivity.

This initial "intensity response" took its toll in an overall loss of productivity. In addition, the long-term effect

of a high intensity response could be expected to produce its own stress effects on health.

Menstrual Cycle

The effects of the 16 kHz pure tone appear to vary depending on the time in the menstrual cycle. The literature indicates that this variation in susceptibility is related to the varying estrogen levels during the menstrual cycle. At times of high estrogen, sensitivity to high frequency sounds and "loudness" increases, thus lowering tolerance and increasing stress.

The statistics in Table 5 show how this seems to work. The college grade point was a significant predictor in the control group, as was the menstrual cycle time: high grades and high estrogen predicting high performance. In the experimental group, grade point was no longer a statistically significant predictor, nor was the menstrual time, but the menstrual time reversed its sign: **high estrogen levels became a liability when the tone was present**. Table 6 also supports this previously hidden effect.

High estrogen normally occurs cyclically at times of high fertility and in the first trimester of pregnancy. It also occurs in women on high-estrogen birth control pills or in those taking estrogen replacement medication after menopause. This information, commonly known by women, is not included in managerial textbooks.[29]

Interaction

The distribution of data in Table 7 supports the hypothesis that the 16 kHz pure tone affects performance. It also demonstrates the importance of the menstrual time in predicting performance on these intellectual tasks with the tone present.

The Median Test shows significance in the interaction within the experimental group of the tone and the estrogen level in total verbal performance, but especially in the second verbal section. Comparison with the control group indicates that even low estrogen women were affected by the tone, and that the intensity response, the ability to overcome the stressor with higher concentration, was more effective for low estrogen women than high. The control group showed a relatively consistent performance throughout, with high estrogen women dominating the above-median distribution.

The Moses Test of Extreme Reaction (Table 8) also shows that even at low estrogen levels, the tone had a significant effect on second-section scores. The test did not show significance for the high estrogen women because the combined effect had already depressed their range in the initial half-hour.

CONCLUSIONS

The presence of the 16 kHz pure-tone emanating from the flyback transformer in computer monitors affects productivity in women within one-half hour of exposure to the sound. The strength of the effect can vary in relation to the estrogen level, with women

at high estrogen levels being more affected.

Although not tested here, it is assumed that the varying loudness of the tone in different monitors can exacerbate or attenuate the effects. How low a dB has an effect? Anecdotally, at least 23 dB, maybe lower.

It is assumed that the overall fall in productivity and the intensity response of speeding up and producing more errors are both responses to the stress effect of the sound on women. The literature also suggests that men whose hearing is excellent at these higher frequencies are likely to be affected.[30]

Many of the earlier studies of the health effects of VDTs on women were abandoned because all the effects could be attributed to general stress in the workplace. This study links stress effects to a specific attribute of the VDTs. The sound-stress effect can be considered an additive stressor which would **increase** normal workplace stress. The estrogen interaction further suggests that those most at risk for stress-related health effects (stress disease) would be those with relatively high estrogen (or on some birth control pills, in early pregnancy or on estrogen replacement therapy). However, since this tone is at the edge of normal hearing, it affects women even at low estrogen and even when they are not aware they are hearing it.

Observations of classrooms and control versus experimental groups indicate either anxiety or general irritation with the environment is the first response to the sound-stress. This may cause women to become less effective as decision-makers or

difficult as co-workers, on a general or cyclical basis, before health or even productivity effects appear.

At the end of Report II, we called for inclusion of the sound-stress effect in any further study of VDT health effects in the workplace. While we encourage further study of electromagnetic radiation and magnetic fields, we reiterate the call for more research into the effects of pure-tone sound. We further urge that women in VDT workplaces be allowed to wear high-frequency earplugs (which attenuate high frequency sounds but allow hearing of conversational tones) until the workplace responds.[31]

Workplace response can take two forms. The first is installation of an electronic circuit that produces the same 16 kHz pure tone but 180 degrees out of phase. The two sounds will cancel each other so that neither can be heard. Some engineers are skeptical about this process. There is no evidence yet that not hearing the sound actually eliminates its effects.

The most effective solution is to change monitors, substituting a high-definition or high-resolution monitor for the offending monitor. High definition monitors operate at twice the frequency, or higher, well above the range of human hearing.[32]

APPENDIX

The early departure of four women from the experimental group while none left the control group may be coincidence, but may also suggest particular susceptibility to the stress of the test conditions.

Table A-1.
Attrition Subjects

Subject	Verbal Score	Quant. Score	All Ss mean	Number Compl.	All Ss mean
523	31		33.63	84	91.21
524		23	23.62	97	77.49
549		27	23.62	78	77.49
556		22	23.62	150	77.49

Table A-2
AVERAGE ACOUSTIC RADIATION LEVELS IN dBA,
EXPERIMENTAL ENVIRONMENT

	20kHz	16kHz	12.5kHz
1989			
Nearest subject	23.8	45.8	28.6
Farthest subject	19.6	39.4	22.4
Tone generator off	0.0	0.0	18.0
1990			
Nearest subject	33.2	49.1	27.2
Farthest subject	26.0	42.1	20.0
Tone generator off	4.2	0.0	17.3

Table A-3
SAMPLE 16 kHz MONITOR OUTPUT AT 1 METER

	dBA
Apple IIc/I	32
Apple IIe/IIe	34
Apple II Plus/Amdek Color I	33
Hewlett-Packard/VGC Display	0
IBM PC/Amdek Model 30	37
IBM PC-AT/Amdek Color I	35
IBM PC-AT/IBM Enhanced Color	36*
IBM PC/IBM 5151	29
IBM mainframe/3278	15.5
Macintosh SE	0
Macintosh 512	0
Tandy 3000HL/Tandy VM-5	23
Xerox 6060/6060-20	0
Zenith/Zenith 1490	0

*With both computer and monitor on, 0 dB.

Table A-4

NON-IONIZING RADIATION DATA
Monitors exhibiting 16 kHz pure-tone, in dB

Manufacturer and model	1/2m-20"	surface
Advanced Systems, TV-5	59.0	91.0
Audiotronics Video, 951-01	55.0	89.0
Audiotronics Video, 940-04	61.0	87.0
Fernseh, Robert Bosch, MC37BB	49.0	81.0
Chuo Musen Co., QDM-9M	53.0	72.0
Chuo Musen Co., QDM-12K	45.0	76.0
Conrac Corp., 5211/C19	61.0	90.0
Control Data Corp., CC-115A	51.0	77.0
Elston Electronics, DM10-09A0	48.0	76.0
Four-Phase Systems, 7101	53.0	73.0
Four-Phase Systems, 5115-7111	50.0	66.0
Hitachi Ltd., CD-12	41.0	54.0
Ikegami Electronics, V591-6022	43.0	69.0
MICO, C3910(2)	56.0	85.0
NEC America, FVM-95A	58.0	79.0
Zenith Radio Corp., D12-NF-1	43.0	68.0
Average	44.6	77.1

Excerpted from: U.S. Dept. of Health and Human Services, An Evaluation of Radiation Emission from Video Display Terminals, Bureau of Radiological Health, FDA 81-8153.

NOTES

1. Winn L. Rosch, "Unsafe at Any Frequency?", MacUser 6:2, 147-151 (February 1990); Paul Brodeur, "The Magnetic-Field Menace," Macworld, 7:7, 136-145 (July 1990).

2. D.S. Chatterjee and A.J. Crookes, "VDUs and Relative Annoyance from High Frequency Noise," Journal of Occupational Medicine, 26:552-53 (No. 8, August 1984).

3. "VDTs and Babies--Apprehensions Persist," The Guild Reporter, Jan. 13, 1984; "NIOSH Urged to Investigate Birth Abnormalities Cluster," The Guild Reporter, Feb. 24, 1984; "Report Said to Back VDT Shielding," The Guild Reporter, April 26, 1985; Henry Weinstein, "Unions, Women's Groups Push for Regulation of VDT Use," Los Angeles Times, Aug. 11, 1985; "OMB Nixes Study of VDTs and Pregnancy," The Guild Reporter, Jan. 10, 1986; "Researchers at Michigan Study Data on VDTs and Pregnancies," The Guild Reporter, Mar. 14, 1986; "OMB Imperils VDT Health Risk Study," Sexuality Today Newsletter 10(25):2, Apr. 6, 1987.

4. Council on Scientific Affairs, American Medical Association, "Health Effects of Video Display Terminals," JAMA, 257:11, 1508-12 (Mar. 20, 1987).

5. Council on Scientific Affairs, p. 1509.

6. Caroline Dow and Douglas C. Covert, "Monitor Tone Generates Stress in Computer and VDT Operators: A Preliminary Study," presented to the Assoc. for Educ. in Journ. and Mass Comm., July 5, 1988, Portland, Ore.

7. Elliott H. Berger, Manager, Acoustical Engineering, E-A-R Division, Cabot Corp., personal communication, Feb. 23, 1987.

8. Council, ibid., p. 1509.

9. U.S. Department of Health and Human Services, An Evaluation of Radiation Emission from Video Display Terminals, Bureau of Radiological Health, FDA 81-8153 (Rockville, Md.: Bureau of Radiological Health, February 1981), pp. 18-19, 34-35.

10. W.I. Acton, "Exposure to Industrial Ultrasound: Hazards, Appraisal and Control," J. Soc. Occupational Medicine, 33:107-113 (1983), p. 110.

11. John D. Durrant and Jean H. Lovrinic, Bases of Hearing Science, 2nd Ed., Baltimore: Williams and Wilkins, 1984, p. 66.

12. Durrant and Lovrinic, Ch. 7.

13. Gerd Jansen, "Effects of Noise on Physiological State," Proceedings of the Conference "Noise as a Public Health Hazard", Washington, D.C.: The American Speech and Hearing Assoc., Feb. 1969, p. 90-1.

14. Alexander Cohen, "Effects of Noise on Psychological State," Proceedings of the Conference "Noise as a Public Health Hazard", Washington, D.C.: The American Speech and Hearing Assoc., Feb. 1969, p. 76.

15. Environmental Noise Measurement, Denmark: Bruel & Kjaer, 1986, p. 12.

16. Cohen, p. 80.

17. Acton, pp. 109-10.

18. W.I. Acton and M.B. Carson, "Auditory and Subjective Effects of Airborne Noise from Industrial Ultrasonic Sources," Brit. J. Industr. Med., 24:297-304 (1967), p. 298.

19. Cohen, p. 75.

20. Diane McGuiness, "Hearing: Individual Differences in Perceiving," Perception, 1:468 (1972).

21. Paul B. Christensen, "Psychoacoustics: The Science of Sound Perception," Broadcast Management and Engineering, April 1987, p. 52.

22. Also note that Truxal says, "Young people with excellent hearing can detect tones up to 20,000 Hz (20 kHz); infants may be able to detect even higher tones." Truxal, John G., The Age of Electronic Messages, New York: McGraw-Hill, 1990, p. 186.

23. Ronald Gandelman, "Gonadal Hormones and Sensory Function," Neuroscience & Biobehavioral Review, 7:1-17 (1983).

24. James Jerger and James Hall, "Effects of Age and Sex on Auditory Brainstem Response," Arch. Otolaryngol., 106:387-391 (July 1980); McGuiness, 1:465-473 (1972).

25. V.T. Wynn, "Measurements of Small Variations in 'Absolute' Pitch," Journal of Physiology, 220:627-637 (1972); K. Paul Satinder and Laura M. Mastronardi, "Sex Differences in Figural After-Effects as a Function of the Phase of the Menstrual Cycle," Psychologia, 17:1-5 (1974); Gandelman, op. cit.

26. Diagnostic ultrasound during pregnancy is an approved medical practice; such exposure is generally considered irrelevant to ultrasound's potential auditory effect.

27. Caroline Dow and Douglas C. Covert, "Interim Report: VDT Pure-Tone and Operator Stress," national convention, International Listening Association, Indianapolis, March 1990.

28. A response of "two weeks ago" is generally interpreted as more than one but less than three, so it should adequately cover the 14th day peak. "Four weeks ago" is generally interpreted as the last week before onset and would cover the decreasing side of the 21st day minor peak. With the wide variability in estrogen peaks among individual women, further studies should be more physiologically precise.

29. See generally: D.S. Thompson, M.D., Everywoman's Health, 4th ed., Englewood Cliffs: Prentice-Hall, 1985, p. 47; Boston Women's Health Collective, The New Our Bodies, Ourselves, New York: Simon and Schuster, 1984, p. 217.

30. Truxal's statement, ibid., suggests an extension from women and some men to children in a household where there is a computer in operation, at day care centers, etc. There are several ramifications here, both psychological and sociological.

31. Some women have responded by wearing personal tape players while at computer terminals. The earphones themselves help reduce the pure-tone intensity, and the added "noise" helps mask the pure-tone.

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